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ESTIMATES OF THE SARDINE SPAWNING STOCK BIOMASS OFF THE GALICIAN AND CANTABRIAN COASTS.

by

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ABSTRACT

From the months of April to May, a simultaneous daily egg production method and acoustic surveys were carried out off the Galician and Cantabrian shelf waters for the purpose of sardine spawning biomass estimation. These surveys, were coordinated on a temporal-spatial scale using two ships, the R/V "Investigador S." doing the egg survey and R/V "Ignat Pavlyunchenkov", the acoustic tracking.

The present document presents the results of sardine biomass estimates from the respective stock evaluation techniques applied: DEPM and acoustics, and analyzes comparatively the results of both approaches.

INTRODUCTION

Sardine (Sardina pilchardus, Walb.) is the target of an important fishery on the Atlantic coast of the Iberian peninsula. Its capture and associated socio-economic infrastructure indicate that it may be one of the most ancient fisheries in this region.

Since 1976 and 1983, two stock evaluation methods (VPA and acoustics, respectively) have been used to assess and manage this fishery (Anon., 1991; Porteiro et al., 1990). In 1988, another stock estimation procedure was introduced, the Daily Egg Production Method (Pérez et al., 1989), based on the methodology described by Lasker (1985).

MATERIAL AND METHODS

In order to carry out the two sardine biomass estimation procedures, two ships were used simultaneously, doing an acoustic survey (R/V "Ignat Pavlyunchenkov") and the egg survey (R/V "Investigador S."). Radio communication between both ships was permanent in order to maximize the temporal and spatial scales.

The egg survey and the acoustic survey cover the area of the Galician and Cantabrian seas, starting from the southern area of the Galician shelf next to the Spanish-Portuguese border (41°55'N) and ending close to the Spanish-French border (Fig. 1a,b).

The egg survey (MPH-90) followed the same sampling scheme as described in Pérez et al., 1989, with a 6 by 6 nautical miles grid of stations. A total of 475 stations were sampled with a Calvet plankton net (Pairovet version, Smith et al., 1985), and the last transect was situated at 2°25'W. Every station recorded surface temperature, wind speed and direction and in a selected station grid, 97 CTD (Seabird model) casts and 44 XBT were done.

Acoustic tracking is based on equidistant radials of 10 nautical miles, perpendicular to the coastline. In the Galician Region, the acoustic tracking had the 200 mts. depth limit, but conditioned to the presence of sardine, whereas, in the Cantabrian region, the track was amplified to the 44° parallel. In this region, oceanographic data collected from 49 CTD casts were done in the area defined by the polygon 7°50'W, 3°50'W and 44°00'N (Fig. 1b).

Echo integration was carried out with a 38kHz EK 400 Simrad and an ES-400 with a color register, and a Simrad QX+QD integrator.

Pelagic trawl hauls for species identification were decided according to echogram registers. Hauls were done at different day times, when possible, for the purpose of obtaining the necessary adult samples for the DEPM. A total of 33 fishing stations were carried out, with 14 positive hauls for sardine. Nevertheless, in some areas close to the coast with significant fish distribution, it wasn't possible to trawl due to rocky seabed or to the presence of fixed commercial fishing gear.

Two kinds of pelagic trawl were used: one with a vertical height of 10 m, and another of 30 m.. The former were used in shallow coastal waters.

Sardine were sampled in two different ways according to the acoustic and DEPM methodology. Sampling was done for length, weight, maturity stages and age in order to estimate the acoustic abundance estimation by length composition and age group.

The estimates of DEPM adult parameters were obtained from hauls between 11:00 and 21:00 GMT. The on board processing of fish was random sampling. In each trawl, 50 fish were sampled to obtain, sex, maturity and measures of standard length for sex ratio. Furthermore, 25 real females per trawl were frozen and their gonads preserved in formalin, and 10 male fish were frozen.

A total of 662 individuals were sampled and 353 ovary were preserved for histological readings. The gonads of all hydrated females caught (total of individuals = 70, proceeding from 7 hauls containing hydrated females) were preserved and the free-ovary body frozen.

Daily Egg Production Model

The sardine spawning biomass estimate is based on Parker's (1980) equation on biomass estimation that was modified by Stauffer and Picquelle for the northern anchovy (Engraulis mordax),

$$B = k\,A\,\frac{P_o\,W}{R\,F\,S}$$

where,

B = spawning biomass in metric tons
P_o= daily egg production (number of eggs per sampling unit, 0.05 m^2.
W = average weight of mature females (grams)
R = sex ratio (fraction mature of females by weight)
F = batch fecundity (mean number of eggs per mature female per spawning)
A = total survey area (in 0.05 m^2 sampling units).
S = fraction of mature females spawning per day

The variance of the biomass estimate is calculated through the delta method (Seber, 1973), as a function of variance and covariance of the estimates of the respective parameters.

Egg production, P_o, is estimated by fitting an exponential mortality function to the data of eggs at age,

$$P_t = P_o \, e^{-zt}$$

where,

P_t = number of eggs per $0.05 m^2$ in age category t
t = age in days measured as the elapsed time from the spawning to the time of sampling
P_o= daily egg production per sampling unit ($0.05\ m^2$)
z = daily rate of instantaneous mortality

By means of an statistical package, the data was fit using a weighted nonlinear least squares regression. Time-zero intercept of the fitted function is the estimate of egg production at spawning. The procedures followed in the egg production estimates is described in García et al. (1991).

The average female weight (W) was calculated as the mean weight of mature females per trawl, using a maximum number of females as a subsample target, which was 25.

Batch fecundity (F) was estimated by regressing batch fecundity (number of eggs per batch) on ovary free weight (W^*) of those females which had hydrated oocytes and without post-ovulatory follicles. This is based on the histological analysis, indicating that spawning had not begun.

Spawning fraction (S) represents the fraction of mature females that have spawned per day. Sardine post ovulatory follicles, have a slow degenerative process (Pérez et al., in prens), and give us the possibility of calculating spawning fraction equal to the average proportion of mature females in the i^{th} trawl which have Day-1 and Day-2 post-ovulatory follicles, Pérez et al. (1989).

Sex ratio (R), was calculated as the weight fraction of mature females of the population. Mature and immature males were included in the analysis. The maximum number of specimens per trawl was 50, from which only the weights of the first 10 males and 25 females were measured. The total weight for sex ratio was obtained as described by Picquelle & Stauffer (1985).

For each of the parameters, mean and variance were estimated following Picquelle and Stauffer's (1985) procedure, calculating average weights since the number of sampled individuals are not equal in each of the hauls.

Acoustic Estimate Method

The survey execution and the estimates calculations followed the methodologies adopted by the Planning Group for Acoustic Surveys in ICES Sub-Areas VIII and IX (ICES, 1986).

During the survey, the acoustic system was calibrated using a copper standard target (Foote et al., 1982) (Table 1). For the conversion factor, the target strength equation was,

$$TS = 20.0 * \log L - 72.6 \text{ (Db)},$$

estimated for herring by Degnbol el al. (1985) and adopted for the Iberian sardine stock.

Absolute abundance estimates were calculated by the equations described in ICES (1986) and based on Nakken and Dommasnes (1975, 1977). For that purpose, total surveyed area was divided into 21 sectors, separated by 20 miles and by different depth strata (0-50, 50-100, 100-200, 200-500). The sector and stratum areas were measured with a planimeter in nm^2.

In each sector the sardine mean density in integrator units per nm^2 was taken as the arithmetic mean of the integrator outputs per nautical mile (zeros included).

The sardine average length distribution within each sector was estimated from the respective survey samples. In those sectors, where sampling was not possible, closest samples representing similar distribution patterns in echograms, as well as, commercial landing samples (3) of sardines caught in the same area and period were used.

The age distribution in each sub-area and the average weight per age was obtained by applying the respective age-length key and the general weight-length relationship. The proportion of mature specimens by age group and length class were also estimated.

The surveyed area was divided into three regions or sub-areas: Region I, corresponds to Galicia area, which extends from the southern limit (Spanish-Portuguese border) to the north. Region II covers the western and central Cantabrian coast, while Region III, corresponds to the eastern Cantabrian area. Sardine spawning biomass estimates through both methods were obtained for each region.

RESULTS

DEPM Estimate

The distributional pattern indicates differences which were taken into account in the regional stratification. Galicia is distinguished by spawning occurring in coastal areas in the mouths of the Rías (south Galicia), whereas, in the western and central part of the Cantabrian sardine egg distribution is widespread and extending to offshore waters (García et al., 1988). The eastern Cantabric shows an intermediate situation, with predominance of a littoral distribution of sardine eggs. The egg distribution of the surveyed area is in Fig. 2.

The procedures followed and results are presented in García et al. (1991). The final stratified estimate of P_0 by regions was as indicated in Table 2.

The average weight of mature females by regions with their corresponding coefficients of variation (Table 2) show an increase of average weight between the two first areas.

The higher Coefficient of Variation (CV) value in Galicia (Region I) can be due to a sample of this region containing very small mature fish, therefore, producing larger weight ranges.

Number of eggs per batch is the basic data set for determining batch fecundity (F). Fig. 3 presents the linear regression fit showing that variance of F is homogeneously distributed, resulting in the equation:

$$F = 370.66 + 389.99\ W^*$$

The average batch fecundity was calculated, and in this case, variance is estimated as described in Draper and Smith (1966, in Piquelle and Stauffer, 1985). The average batch fecundity was calculated with hydrated females between 32 gr. and 109 gr. and the mean value was 29,270.04 (standard error = 822.5). No atretic hydrated oocytes were found in any of histological observations, and in consequence, showing no bias by atresia in batch fecundity. The final estimate of this parameter is in Table 2.

The mean relative fecundity (number of hydrated oocytes per gram of female weight was 389.7 (standard error = 10.74).

The following table shows the spawning fraction values by two different post-ovulatory follicle ages by regions and their respective coefficients of variation.

	Galicia I	W Cant. II	E Cant. III
Day-1	0.10	0.11	0.20
c.v.	0.32	0.91	0.20
Day-1+Day-2	0.12	0.09	0.23
c.v.	0.19	1.04	0.30

No oversampling of follicles Day-0 were found. Because of this, the total number of mature females has not been corrected. In this year, Day-1 post-ovulatory follicles was used to define spawning fraction, because no big differences were found between Day-1 and Day-2 post-ovulatory follicles.

High coefficients of variation (CV) were found in region II, probably due to the insufficient number of hauls in this area.

The results sex ratio estimates are shown in Table 2. Sex ratio calculated for the entire survey area is 53%. High CV values were found in region II and III due to the low number of samples in this area.

The DEPM equation was used to estimate the total spawning biomass of sardines in the spanish North Atlantic coast and the value was 74,200 tonnes. The estimate of spawning biomass by regions is shown in Table 1. The resulting spawning biomass estimate was calculated as the sum of the each of the regions, resulting in 77,720 tonnes, this estimate is no very different from the unregionalized value.

Acoustic Estimate

The acoustic biomass estimate by age group, length class and regions are in Table 3 and Fig. 4. Fig. 5 represents the distribution of sardine in the surveyed area. The total sardine biomass was estimated as the sum of each of regions, resulting in 96,500 tons. Greatest abundance estimates correspond to northern Galicia which represented 38% in weight to the total area. The lowest biomass estimate by region corresponds to the eastern Cantabrian (17,485 tons). However, a sub-region of Galicia, defined as southern Galicia, off the Rias produced a low biomass estimate 7,868 tons.

Age group III and VII represented 50% in number and in weight of the total area, corresponding to the 1987 and 1983 year classes, respectively. Age group I was mainly distributed in south Galicia and in a minor proportion in region III. Age group IV+, were concentrated in northern Galicia and the central Cantabrian (Regions I and II).

Sardine is distributed along the continental shelf of the survey area. Nevertheless, in the western Cantabrian, sardine schools were detected in offshore waters (30 miles). In northern Galicia, sardine was located over rocky seabed close to the coast.

DISCUSSION

Sardine spawning occurs off the Cantabrian Sea, mainly in its western end and in its central area, off the proximities of Santander, as shown in previous studies (García et al., 1988, Pérez et al., 1989). The 1990 sardine egg distribution is analyzed in García et al. (1991).

The egg distribution pattern (Fig. 2) is similar to the 1988 DEPM, although showing in the whole, less abundances, and presenting a major proportion of negative tows. The major spawning centers are located in offshore areas in northern Galicia, the western Cantabrian area and in the coastal regions of the central region off Santander.

DEPM adult data show an increment towards the east of the mean female weight between the two first regions, but if we exclude a sample of this region containing very small mature fish the value of mature female weight is the same than in regions I and II. These results are different to the 1988 DEPM, because in this case, regions II and III, have practically identical values. The mean female weight of all the area is approximately the same as in 1988. Mean weights obtained by acoustic sampling for the whole population (male and female) (Table 3) show higher values in some regions, and the trend between regions is not similar.

Higher values of batch fecundity are observed in Regions II and III, due to larger size classes in the sardine population within this region. Relative fecundity estimates off 1988 and 1990 present significant differences between both years, with smaller relative fecundity and Daily Specific Fecundity in 1990:

Year	1988	1990
Daily Specific Fecundity (10^8 eggs/day-tonnes)	31.97	17.82

This produced smaller batch fecundity values in 1990 for the total area and also by regions. Batch fecundity can vary considerably between years and also during the spawning season (Alheit, 1988), so the differences could possibly respond to changes in the spawning peak period, or to different environmental conditions.

The spawning fraction obtained registers quite pronounced differences between regions. Region I and II is in the order of 0.10, while in region III is 0.20. This means that each batch is spawned every 5 days in region I and II, while every 10 days in region III. The same behavior was observed in the spawning fraction of sardines during DEPM in 1988, with strong differences in region I. This means that different reproductive patterns can occurs with mature female adults of the same weight in close regions. No abnormal situation was observed in region I in comparison with the 1988 DEPM results, in agreement with the hypothesis that in 1988 some bias could exist in the sampling of this region, with a high proportion of mature female in spawning condition and low proportion of female, (Pérez et al 1989).

In the Atlantic Iberian coast, the fraction of mature sardine females with < 48 hours old post-ovulatory follicles was 0.12 (standard error 0.0101), indicating that the mean interval between each spawning was approximately 8 days.

Sex Ratio of all regions were close to 50%, with clear differences with the 1988 DEPM where the region I presented an anomalous low sex ratio.

The daily specific fecundity is close to the half obtained in 1988 for: a low bach fecundity, a low proportion of mature females and a light higher spawning fraction.

Comparing the acoustic and DEPM results, these show differences between regions, mainly corresponding to regions I and II. This can be explained by the fact that the main spawning grounds are located in the margin of both regions. Nevertheless, the sum of regions I and II by the acoustic and DEPM estimate produce similar values (79,015 and 70,357). The greatest difference appears in Region III, but it could be due to a lesser sampling effort in the egg and adult survey, and also to a greater temporal gap in the coverage of this area between both ships. In any case, in general the trends between regions by both methods of estimation are similar.

The 1990 spawning biomass estimate of spanish north-atlantic sardines is less than half of the 1988 estimate (Table 3). The VPA indicates that the sardine stock (VIIIc and IXa ICES divisions), has been stable since 1983 to 1987, with a decrease in the catch level. In spite of this poor recruitment, the SSB has decreased since 1985. (Anon. 1991)

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SHIP : IGNAT PAVLIUCHENKOV	DATE : 19/04/1.990
PLACE : RIA DE VIGO	DEPTH : 33 m
ECHOSOUNDER : EK-400	TRANSDUCER : Split Beam
FREQUENCY : 38 KHz	SPHERE TS : -33.6 dB
W. TEMPERATURE : 13º C	SOUND V. : 1.498 m/s
SPHERE DEPTH : 22 m	r = t * c/2 = 16.5 m

	40 log r	20 log r	
CONSTANT (TVG)	99.1	64.6	dB
LOSS TRANSMISSION AT DEPTH r	48.7	24.35	dB
ATTENUATION TVG AT DEPTH r	50.4	40.25	dB

GAIN SELECTED		-10		dB
GAIN MEASURED		-10		dB
POWER OUTPUT		High		
SIGNAL DURATION		1		msec
BANDWIDTH		Wide		
ECHO LEVEL	0.84		2.7	V_{p-p}
20 log U/2 √2	-10.54		-0.40	dB

SL+VR = U-TL+2TL40-G-TVG = -10.54+33.6+91.1+10+48.7 = 172.86

SL+VR = U-TL+2TL20-G-TVG = -0.4+33.6+64.6+10+24.35 = 132.15

$M_{theoric} = V_{p-p}^2/2*(c*z)/2*15.5*0.7 = 7.41$ mm

$M_{Integration} = 7.55$ mm

Table 1. Calibration results of acoustic gear.

	Galicia I	W Cant. II	E Cant. III
P_o (eggs/0.05m^2)	1.1454	1.7784	4.248
Standard error	0.3927	0.4544	0.9242
Ave. Female Weight			
W (gr.)	68.14	83.65	83.61
C V	0.12	0.02	0.01
Batch fecundity			
F	26 946.96	32 980.32	32 976.92
C V	0.26	0.19	0.20
Spawning Fraction			
S (Day-1)	0.10	0.11	0.20
C V	0.32	0.91	0.20
Sex Ratio			
R	0.56	0.53	0.45
C V	0.08	0.38	0.28
Spawning Biomass (tonnes)	24 232	46 125	7 363
C V	0.40	0.72	0.27

Table 2. Estimates of DEPM parameters , variances, coefficients of variation by region and total area in 1990.

Age Groups	GALICIA I Biomass (tonnes)	Mean Weight	W. CANT. II Biomass (tonnes)	Mean Weight	E. CANT. III Biomass (tonnes)	Mean Weight
I	1866	40.96	5	65.38	1067	45.51
II	2194	66.07	540	78.48	989	62.13
III	12388	77.42	5065	81.45	6845	75.77
IV	2445	81.38	1155	83.82	755	79.48
V	4338	88.25	2135	89.35	1258	86.83
VI	6771	94.32	3868	94.90	2073	97.20
VII	12957	93.99	7041	95.06	3667	96.67
VIII	3819	98.70	2156	99.21	1326	102.90
IX	2412	99.22	1472	99.51	993	102.42
X	2413	101.94	1366	102.95	884	105.53
XI	1252	103.26	653	104.05	467	106.18
XII	470	103.76	235	103.66	161	104.94
TOTAL	**53325**	**84.51**	**25690**	**91.76**	**17485**	**83.17**

WHOLE AREA

Age Groups	Biomass (tonnes)	Mean Weight (g)
I	2938	42.53
II	3724	66.47
III	21298	78.03
IV	4354	81.67
V	7731	88.31
VI	12712	94.95
VII	23666	94.71
VIII	7300	99.59
IX	4877	99.94
X	4662	102.89
XI	2373	104.04
XII	866	103.97
TOTAL	**96500**	**86.07**

Table 3. Sardine abundance per age and mean weight in each sub-area and the total.

	GALICIA I	W. CANT. II	E. CANT. III	TOTAL
1988				
DEPM. SSB	134.195	33.503	12.467	180.165
C.V.	0.66	0.30	0.56	0.50
1990				
DEPM. SSB	24.232	46.125	7.363	77.720
C.V.	0.40	0.72	0.27	0.50
1988				
ACOUSTIC B.	102.394	58.010	13.612	174.016
1990				
ACOUSTIC B.	53.325	25.690	17.485	96.500

Table 4. Sardine biomass estimated in 1988 and 1990 by the DEPM and Acoustic methods.

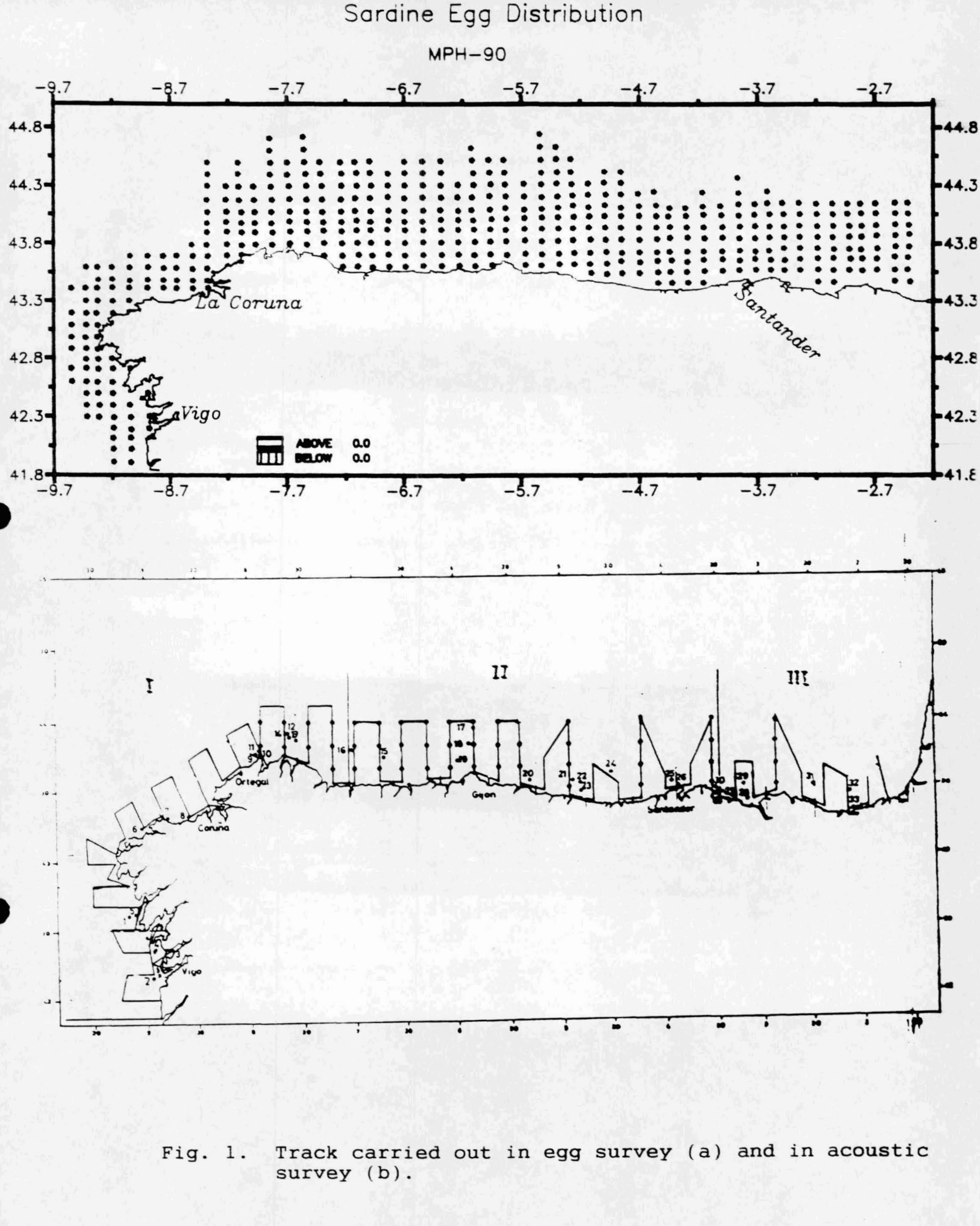

Fig. 1. Track carried out in egg survey (a) and in acoustic survey (b).

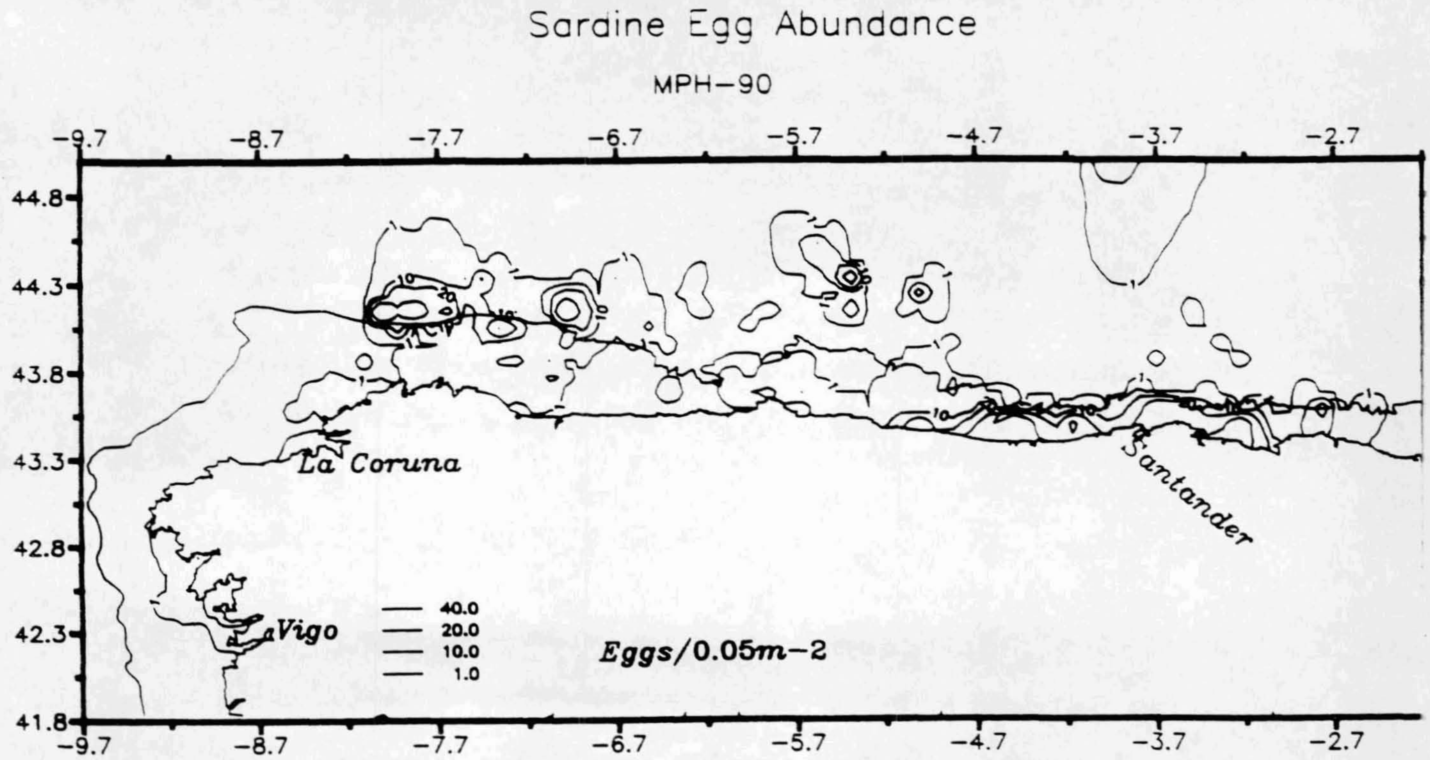

Fig. 2. Egg distribution of the surveyed area.

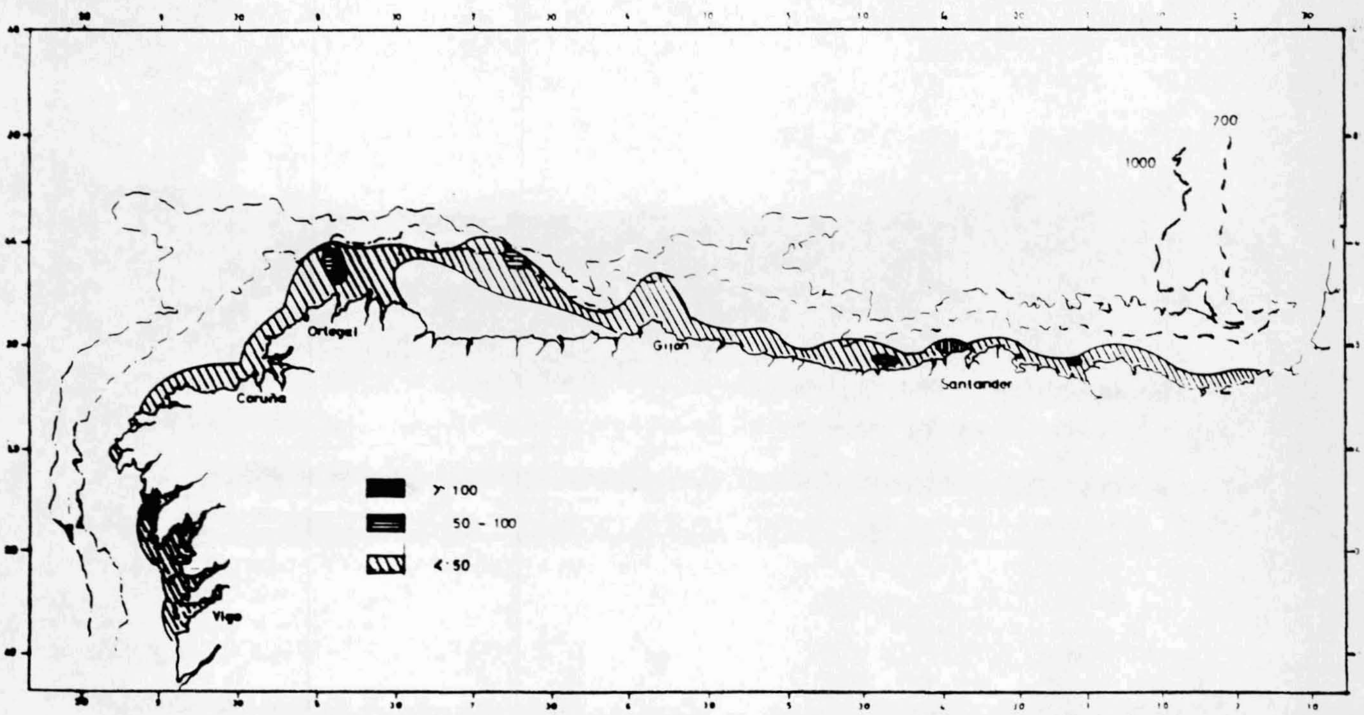

Fig. 5. Adult sardine distribution of the surveyed area.

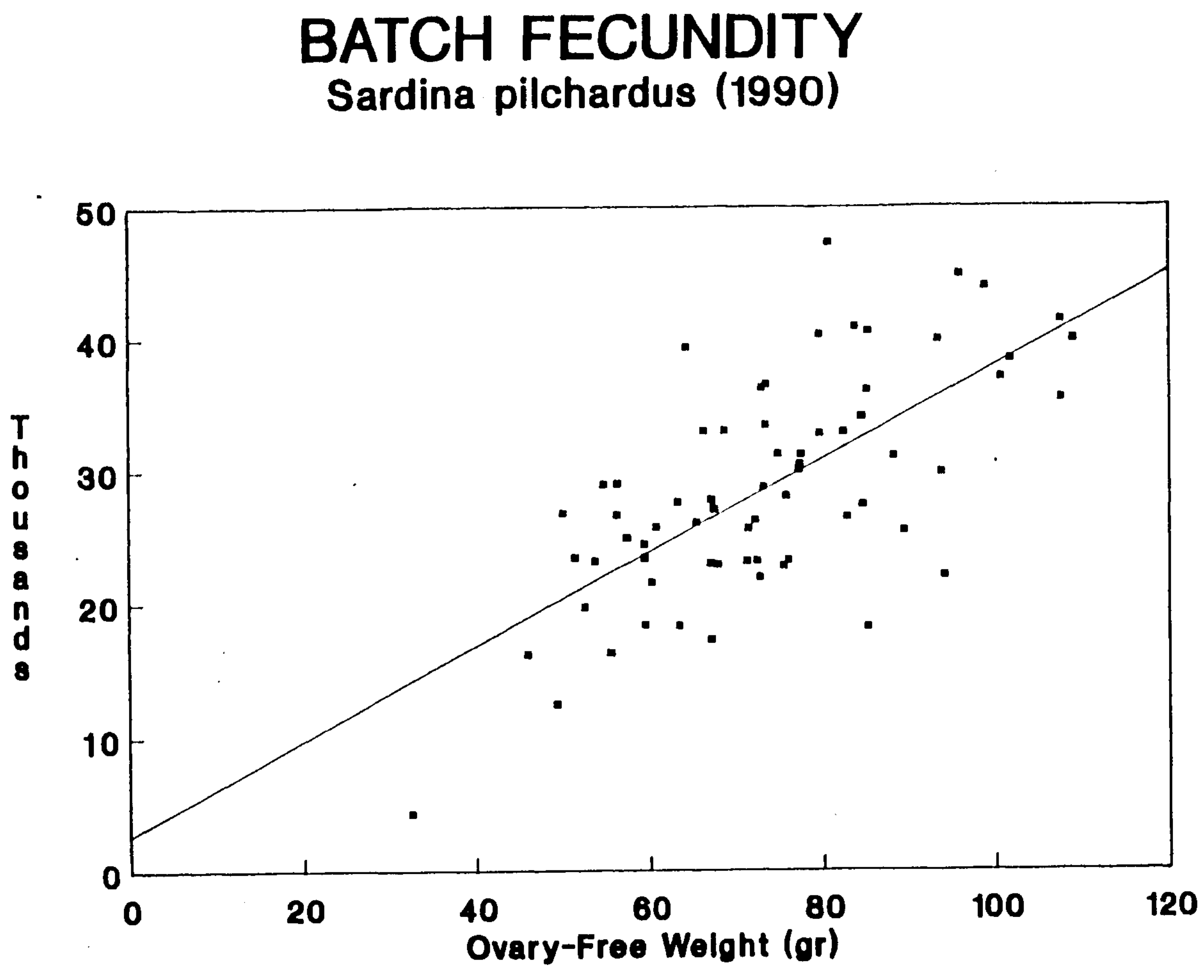

Fig. 3. Relationship between ovary-free weight and batch fecundity of *Sardina pilchardus*.

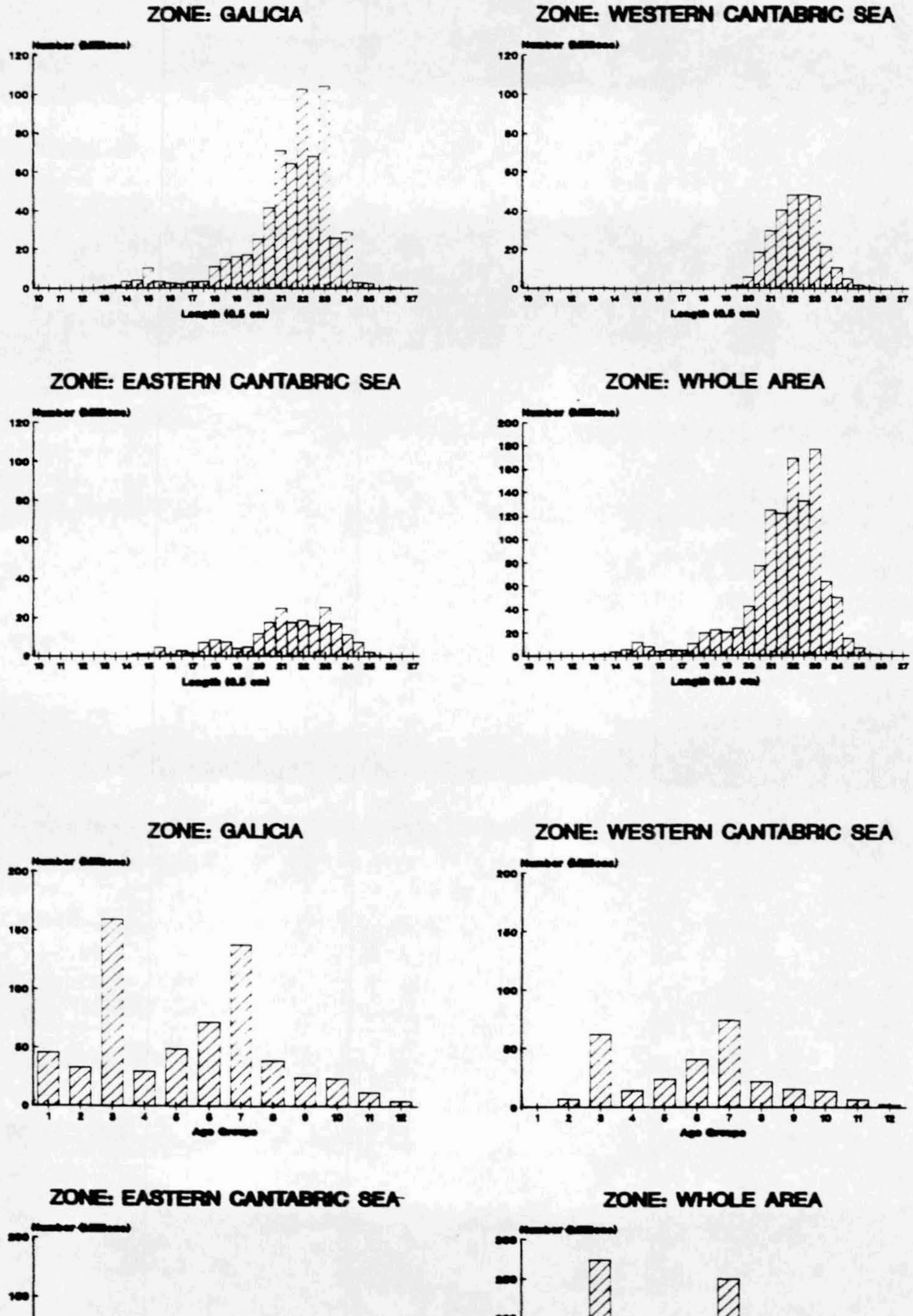

Fig. 4. Acoustic biomass estimated by age group and by length class for regions and total area.